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Document Title **CAL Flight Module Vibration Test Report**		

REVIEW COPY

Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT)

Calorimeter Flight Module 101 Vibration Test Report

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CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes
01	15 October 2004	Initial Release

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1 INTRODUCTION

1.1 PURPOSE

This report presents the results of the protoflight structural environment test performed on the GLAST Calorimeter (CAL) Module, designated as Flight Module 101 (FM 101). This test was performed on September 22-24, 2004 in accordance with LAT-PS-04454-02, *CAL Flight Module Vibration Test Procedure*, and work order, WOA-01379.

1.2 OBJECTIVE

The objective of this test is to verify the design and workmanship of the GLAST CAL Module protoflight unit, FM 101, in accordance with the Large Area Telescope (LAT) Program Instrument Performance Verification Plan, LAT-MD-00408. The design and workmanship was verified by subjecting FM 101 to a protoflight test program, which subjected the CAL Module to test levels that exceeded the maximum expected launch and ascent dynamic environments. The fundamental frequency of the CAL Module was verified by subjecting it to low-level random vibration. The environments were simulated by random vibration, sine-sweep and sine-burst test.

1.3 OVERVIEW

Structural environment testing was conducted at the Vibration Test Laboratory of the Payload Check-Out Facility (Building A-59) at the Naval Research Laboratory, Washington, D.C. Testing consisted of the standard NRL-approved technique of attaching the test article to either a slip table or vertical head expander and conducting a series of vibration tests of various levels and types.

FM 101 was successfully subjected to protoflight level structural environments. Response limits were adjusted to ensure that the test article was not over-tested and met the minimum predicted environments.

The fundamental frequency was characterized before and after subjecting the CAL Module to the protoflight level structural environments. Negligible differences were seen between the pre- and post-test signatures.

Following environmental testing, comprehensive electrical performance testing and muon collection was conducted. With the exception of the non-flight TEM-TPS assembly, no anomalies were noted. Following testing, the structure underwent a through visual inspection. Again, no anomalies were noted.

Therefore, FM 101 is considered to have successfully passed the CAL Flight Module Vibration Test and thus, considered acceptable for flight.

2 APPLICABLE SPECIFICATIONS

Documents required to perform this test include the as-run procedure and the work order. The applicable documents cited in this standard are listed in this section only for reference. The specified technical requirements listed in the body of this document takes precedence over the source document is listed in this section.

2.1 GOVERNMENT SPECIFICATIONS

The following specifications, standards and handbooks are for reference only.

Number	Title
GEVS-SE	General Environmental Verification Specification for STS & ELV Payloads, Subsystems, and Components

2.2 NON-GOVERNMENT SPECIFICATIONS

Number	Title
LAT-MD-00408	LAT Program Instrument Performance Verification Plan
LAT-MD-01370	CAL Comprehensive and Limited Performance Test Definition
LAT-PS-01513	CAL Functional Test and Calibration Procedure
LAT-PS-04237	CAL Module Handling Procedure
LAT-PS-04454	CAL Flight Module Vibration Test Procedure
LAT-SS-00788	LAT Environmental Specification
LAT-SS-01345	CAL Module Verification & Environmental Test Plan
LAT-TD-01888	CAL Module – Engineering Module (EM) Vibration Test Report
SAI-TM-2378	Pre-Test Analysis Report for CAL EM3 Module (11 Feb 2003)
N/A	Instrumentation Manuals

2.3 DRAWINGS

Number	Title
LAT-DS-00916	Calorimeter Module, GLAST
LAT-DS-04536	Tower Module, Calorimeter, GLAST

2.4 ORDER OF PREFERENCE

In the event of a conflict between this document and the technical guidelines cited in other documents referenced herein, the technical guidelines of this document would take precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3 TEST DECRIPTION

3.1 TEST OBJECTIVE

The objective of this test is to verify the design and workmanship of the GLAST CAL Module protoflight unit by verifying the fundamental frequency and subjecting it to test levels that exceed the maximum expected launch and ascent dynamic environments.

3.2 TEST METHODOLOGY

The structural environmental test was divided into four tests, which were performed on each of the three axes of the protofight unit: the transverse axes (X and Y) and the thrust axis (Z). The four test activities of the structural environmental test are:

- Frequency Survey – FM 101 was subjected to a low-level random vibration environment to define a pre-test and post-test signature of the test article.
- Random Vibration Test – FM 101 was subjected to the dynamic environment defined by the protoflight random vibration acceleration spectral density.
- Sine-Sweep Test (Sinusoidal Vibration Test) - FM 101 was subjected to the dynamic environment defined by the protoflight sine-sweep spectrum.
- Sine-Burst Test - FM 101 was subjected to a protoflight static-equivalent acceleration level defined by the protoflight sine-burst test level

The fundamental frequency of FM 101 was verified by evaluating the frequency response function measured while subjecting the test article to a low-level random vibration environment. This activity defined the pre-test signature of the test article prior to subjecting it to the test environments. Accelerometer data was reviewed following the test to determine locations with high response.

The next test in the test flow was the random vibration test. The random vibration test was also divided into three phases. The first phase subjected the test article to the –12 dB of the full random vibration level to verify notching criteria. The second phase subjected it to an intermediate random vibration level (–6 dB), which would verify the response limits if the notching was to be adjusted. The third phase subjected the test article to the full random vibration level.

Following random vibration test activities, the test article was subjected to a sine-sweep test. The first phase subjected the test article to the –12 dB of the full sine-sweep level to verify notching criteria. The second phase subjected the test article to an intermediate sweep level (–6 dB) and the third phase subjected it to the full sine-sweep level.

The test article was then subjected to a protoflight static-equivalent acceleration level by means of a sine-burst test.

A final low-level random vibration, which was run following the sine-burst test defined the post-test low-level signature of the test article. Comparison of the frequency response functions before and after this test is used to determine that no structural change occurred to the test article.

Following structural environmental testing, a comprehensive performance test (CPT) of the AFEE and TEM electronics was performed in accordance with LAT-PS-01513, *CAL Functional Test and Calibration Procedure*. This test establishes that proper communication between TEM and CAL still exists, that all registers of the CAL function properly, that pedestal amplitude and noise in all four energy ranges remain stable, and that the optical performance of each CDE remains stable. These results are then compared to the reference CPT, which was conducted prior to entry of the CAL Tower Module into the environmental test program.

3.3 TEST ARTICLE DESCRIPTION

The test article is the GLAST CAL Tower Module, FM 101, as documented in the as-built configuration list (ABCL). The CAL Tower Module (LAT-DS-04536) consists of the CAL Module (LAT-DS-00916) with the Tower Electronics Module/Power Supply (TEM/TPS) Assembly (LAT-DS-01643) attached to the CAL Module base plate by means of four rigid stand-offs. The total weight of this unit is approximately 206 lbs.

There are no deviations from the flight configuration with the exception of:

- Electrical Harness from the TPS is removed.
- The TEM/TPS Assembly is version EM2, rather than Flight.

The GLAST CAL Module in flight configuration is shown in Figure 3-1.

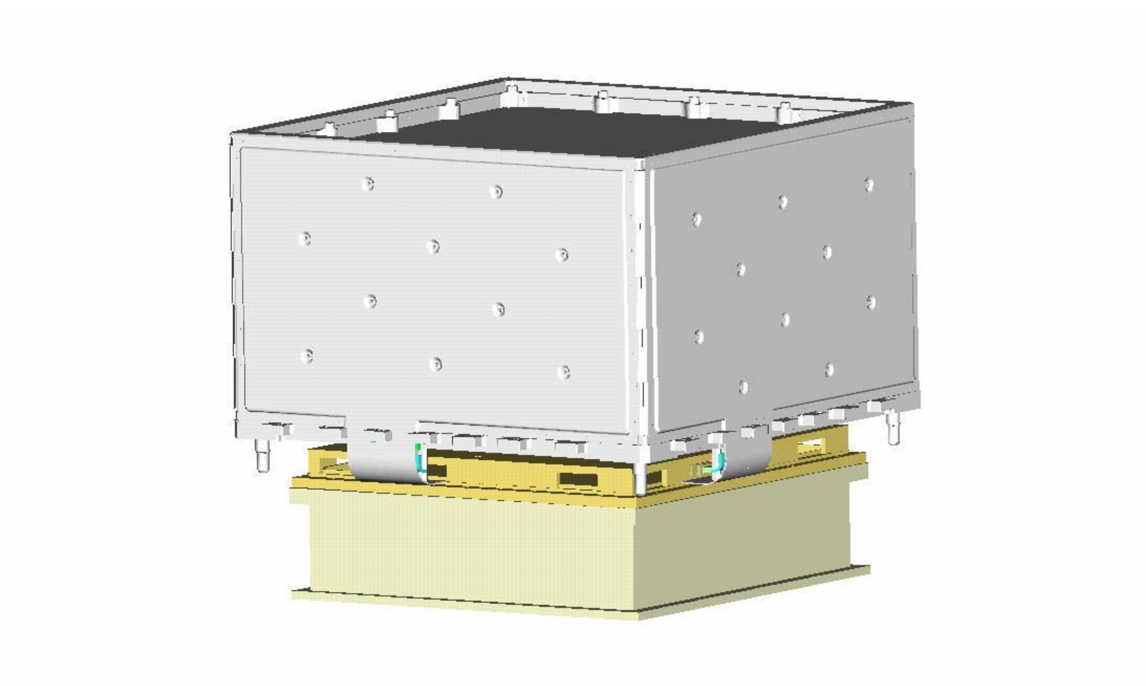


Figure 3-1: CAL FM in Flight Configuration with TEM/TPS

4 TEST RESPONSIBILITIES

4.1 TEST PERSONNEL

The following personnel participated in the vibration test of Test personnel are defined below. Responsible points of contact for this test procedure are listed in Table 4-1.

Table 4-1: Test Personnel

Role	Name	Telephone Number
Project Representative	Eric Grove	202-767-3112
Test Director	Paul Dizon	202-404-7193
Test Conductor, Primary	Bob Haynes	202-767-0705
Test Conductor, Electrical Subsystem	Byron Leas	202-404-1464
Test Conductor, Science Subsystem	Eric Grove	202-767-3112
Instrumentation/Data Support	Jim Layher	202-767-0705
Analysis Support	Jon Shaw	301-902-4260
	Jim Haughton	202-767-4689
	Chuck Williams	202-767-6696
Quality Assurance Support	Nick Virmani	202-767-3455
	James Lee	202-404-1476

5 GENERAL TEST PROGRAM REQUIREMENTS

5.1 TEST SETUP

5.1.1 Test Location

The structural environmental test will be conducted in the Vibration Test Laboratory of the Payload Check-Out Facility, Building A-59, at the Naval Research Laboratory, Washington, D.C.

5.1.2 Test Article Configuration

The CAL Tower Module will be mounted in the upright position onto a two-piece vibration test fixture. The two-piece test fixture consists of a CAL base plate adapter and the primary fixture, which mounts directly to the slip table of the vibration table. The As-Built Configuration List (ABCL) of the CAL Tower Module in its test configuration is shown in Table 5-1.

Table 5-1: As-Built Configuration List – Vibration Test

Assembly / Component	Part Number	Status
Calorimeter Tower Module, s/n FM 101	LAT-DS-04536	Flight
TEM/TPS Assembly, s/n FM01	LAT-DS-01643	GSE
M6 Screws, Socket-Head Cap (QTY 4)	LAT-DS-04385	GSE
M6 Washers, Flat (QTY 4)	LAT-DS-04354	GSE

5.1.3 Test Equipment

The following test equipment and systems will be used in the execution of this test:

- Test Article: GLAST CAL Tower Module (LAT-DS-04536) -
  (CAL Module, EM-2 TEM-TPS electronics box, SIU mass simulator)
- Test Article Support: CAL Vibration Test Fixture (LAT-DS-01314)
  CAL Vibration Test Fixture Interface Plates (LAT-DS-01518, LAT-DS-01519)
  CAL Lift Fixture Assembly (LAT-DS-04138)
- Accelerometers: Endevco Model TBD Piezoelectric Tri-Axial Accel
- Charge Amplifiers: Endevco Model 2775A Charge Amplifiers
  Unholtz Dickie Model D22 Charge Amplifiers
- Vibration Test System: Ling Electronics Electrodynamic Shaker
  GenRad Model 2550 Vibration Control System
  Ling Model 8096B Power Amplifier
  Ling Model SSW-1340-230s Switching Unit
- Data Acquisition System: Hewlett Packard VXI Data Analysis System

- CAL Electrical Ground Test Equipment

Any substitution of the designated test equipment will require the approval of the test director and/or the test conductor, and the quality assurance engineer. Such substitutions will be noted as part of the test data and submitted with the test report.

The test fixture, as shown in Figure 5-1, supports the CAL Tower Module in the upright position. Since the CAL Tower Module must be removed from the test fixture each time the assembly is re-oriented for each axis test, the CAL Tower Module is attached to the test fixture via bolt-on interface plates, as shown in Figure 5-2. These plates are attached to the tabs of the CAL Module base plate. Because there are 56 fasteners connecting the CAL Tower Module to the interface plates, the bolt-on feature of the plates facilitates the re-orientation process. After the interface plates are installed onto the base plate of the CAL Module, the shear pins are secured via shear plates, as shown in Figure 5-3.

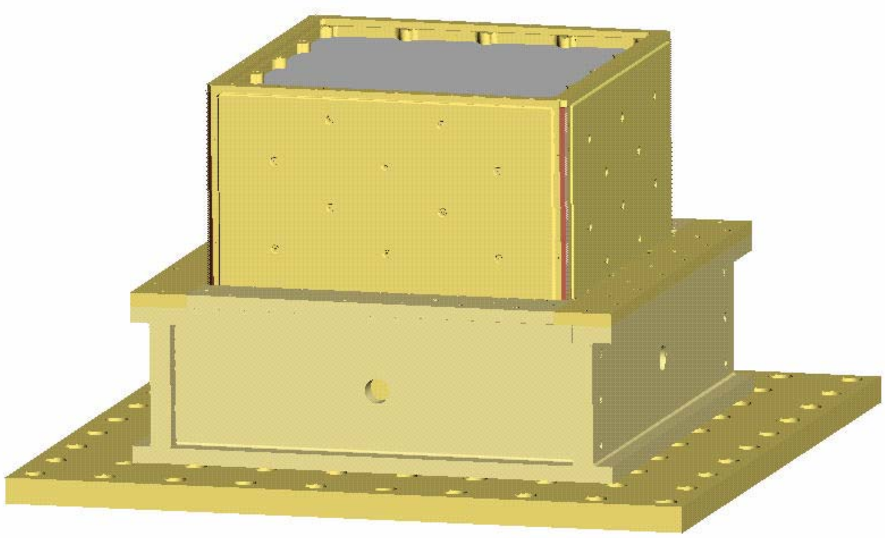


Figure 5-1: Test Fixture with FM CAL Module

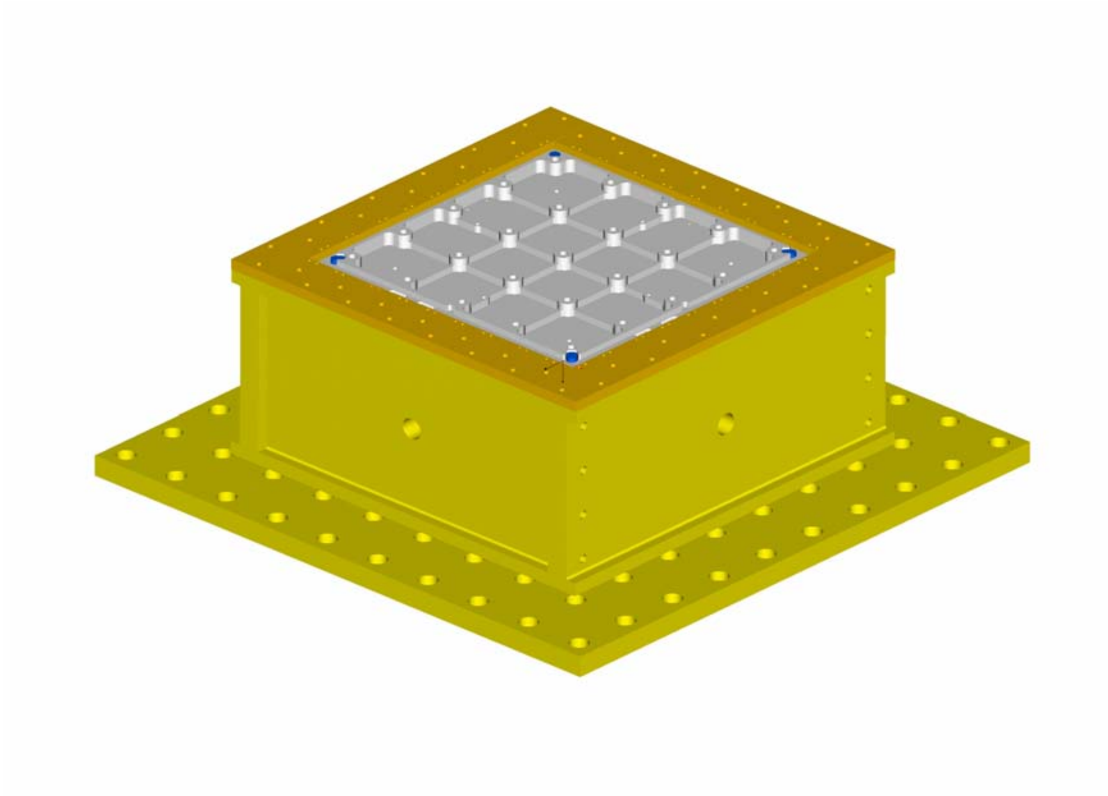


Figure 5-2: Test Fixture Showing Interface Plates

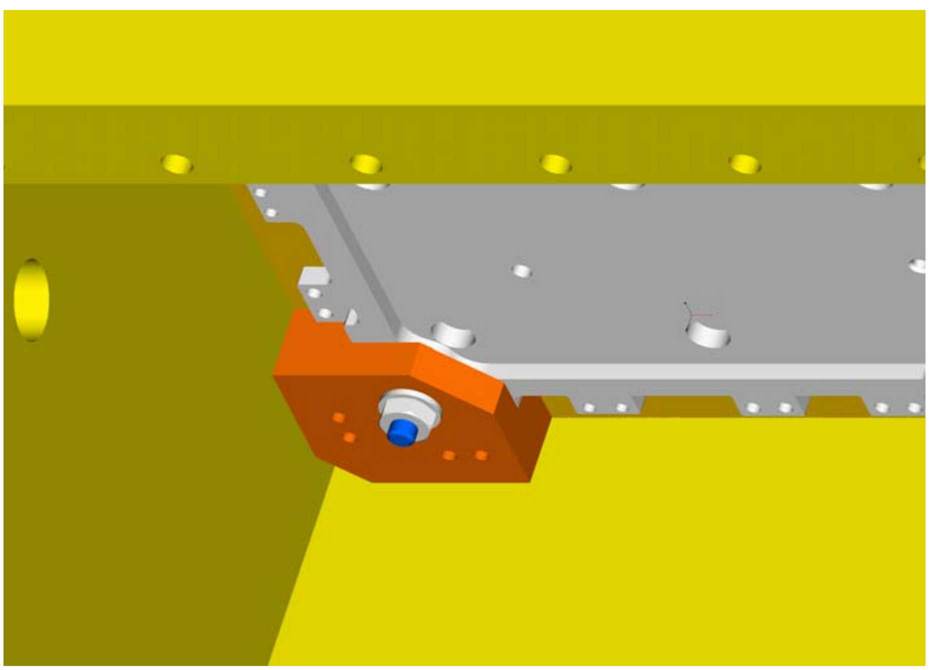


Figure 5-3: Test Fixture Showing Shear Plate Interface

5.2 INSTRUMENTATION AND DATA ACQUISITION

5.2.1 Instrumentation

Three uni-axial and three calibrated tri-axial accelerometers were used to measure the acceleration response of FM 101. These accelerometers were attached at points of interest or at points expected to have high acceleration response where response limiting was expected. Furthermore, two calibrated tri-axial accelerometers were attached at opposing corners of the CAL Tower Module-test fixture. Two pairs of uni-axial accelerometers were attached to the interface plane (one pair) and the base plate (one pair) of the test fixture for shaker control.

Table 5-2 lists the accelerometers that are to be used in this series of testing. All accelerometers are to be aligned with the CAL coordinate system shown in Figure 3-1. Accelerometer locations are illustrated in Figure 5-4.

Some of these accelerometer channels were monitored during the random vibration testing of the CAL to response limit components with known limitations such that random vibration levels do not exceed EM component test levels.

5.2.2 Calibration

NRL standard vibration laboratory calibration techniques were used to calibrate all test equipment. All accelerometers were calibrated by comparison against a “Standard Accelerometer” traceable to the National Institute of Standards and Technology and verified by QA.

5.2.3 Data Acquisition

All data was acquired through the VXI Data Acquisition System. The data is stored on the HP VXI computer in digital format with a sampling rate appropriate for a 2000 Hz minimum bandwidth.

5.2.4 Data Reduction

Time history data was stored and analyzed on the HP VXI using SDRC/IDEAS test software. Frequency response functions were generated and stored. All data was analyzed over the 10 to 2000 Hz frequency range. In addition, response power spectral densities and cumulative G_{rms} and Force RMS plots for each channel were generated to monitor the response levels during testing. These data plots contain test description, test date, and name and channel number.

Table 5-2: Accelerometer Locations

Accelerometer ID	Channel ID	Location	Degree of Freedom
1	01X 01Y 01Z	-X Side Panel – Top	X Y Z
2	02X 02Y 02Z	-Y Side Panel – Top	X Y Z
3	03X 03Y 03Z	+Z Structure	X Y Z
5	05X 05Y 05Z	Aft Surface of SIU Mass Simulator	X Y Z
7	07X 07Y 07Z	+X,-Y Interface Plate - Test Fixture	X Y Z
8	08X 08Y 08Z	-X,+Y Interface Plate - Test Fixture	X Y Z
10	10X, 10Y, or 10Z	Vibration Fixture (Control) - Interface	X, Y, or Z
11	11X, 11Y, or 11Z	Vibration Fixture (Control) - Interface	X, Y, or Z
12	12X, 12Y, or 12Z	Vibration Fixture (Control) - Base	X, Y, or Z
13	13X, 13Y, or 13Z	Vibration Fixture (Control) - Base	X, Y, or Z

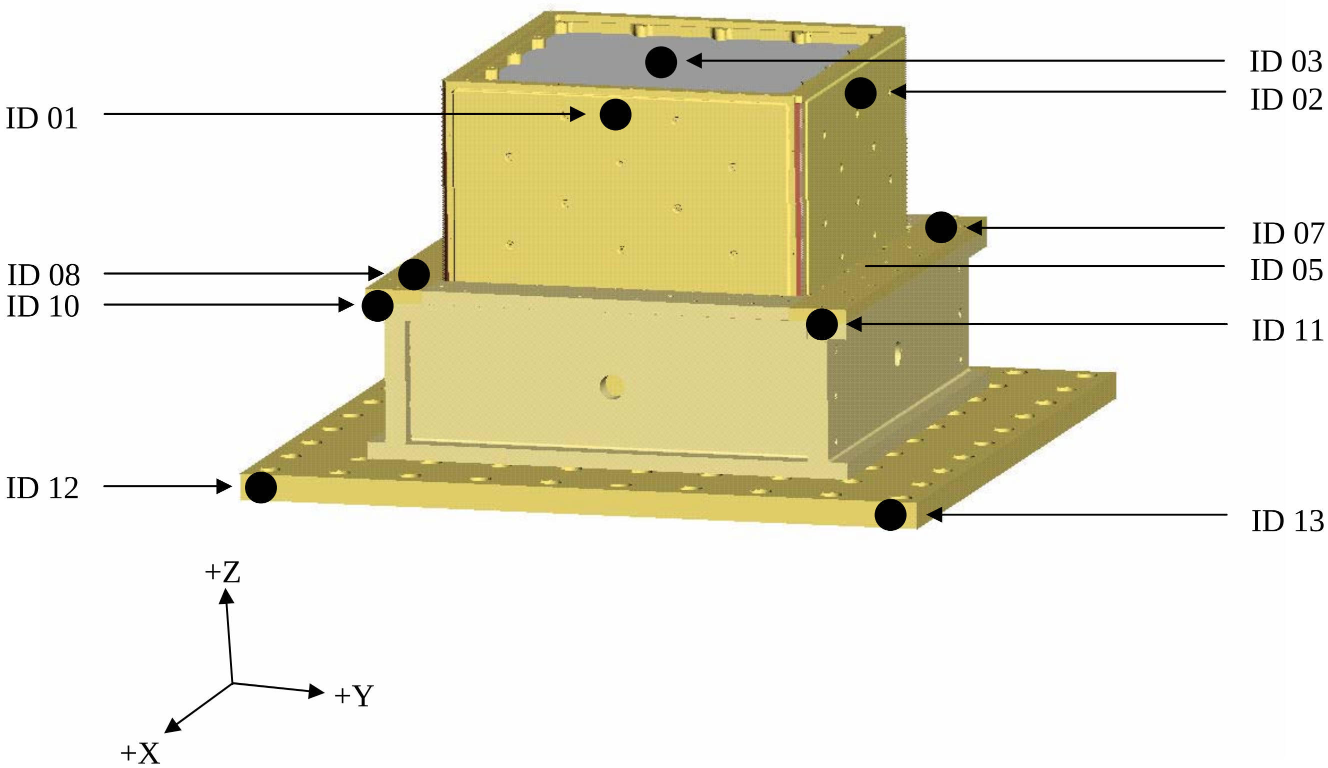
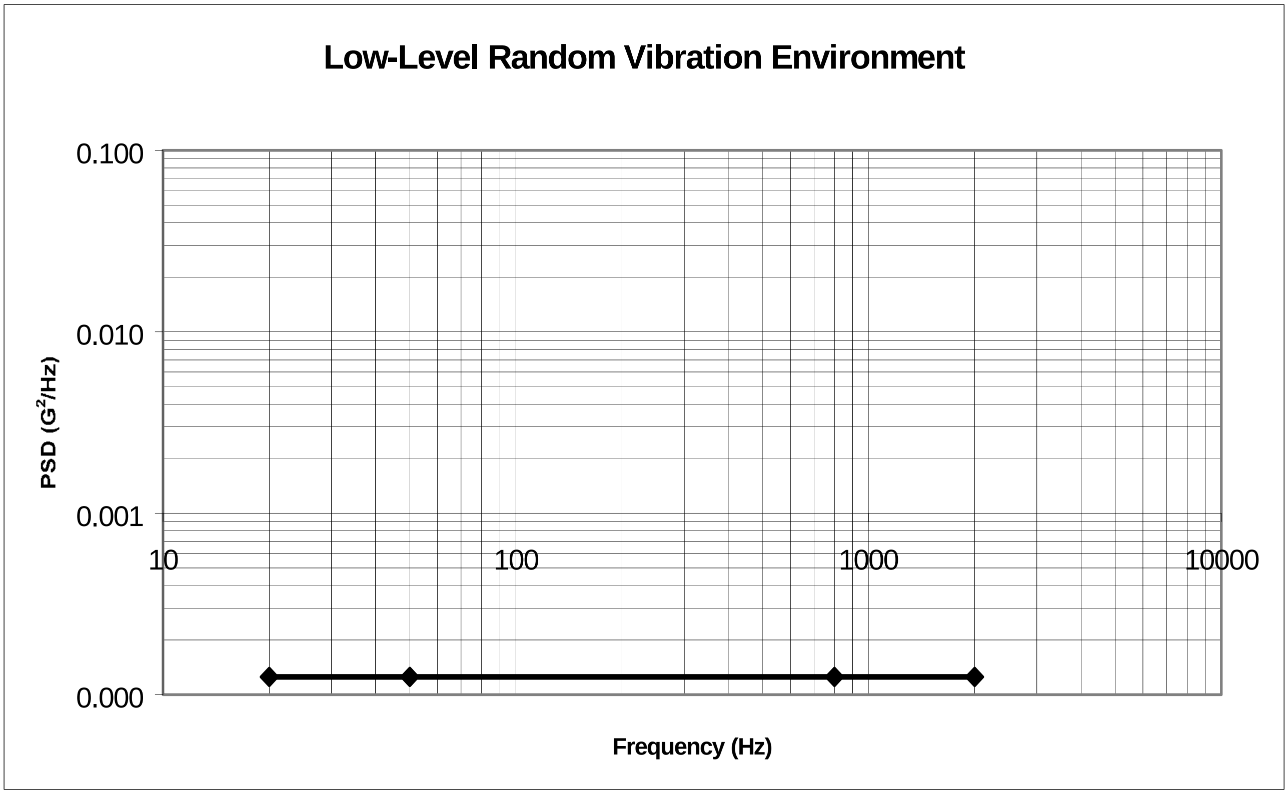


Figure 5-4: Accelerometer Locations

6 TEST LEVELS

6.1 LOW-LEVEL RANDOM VIBRATION FOR FREQUENCY SURVEY

All three axes of FM 101 was independently subjected to low-level random vibration for frequency identification and system characterization before and after the test activities. Figure 6-1 contains the low-level random vibration spectrum that was used.



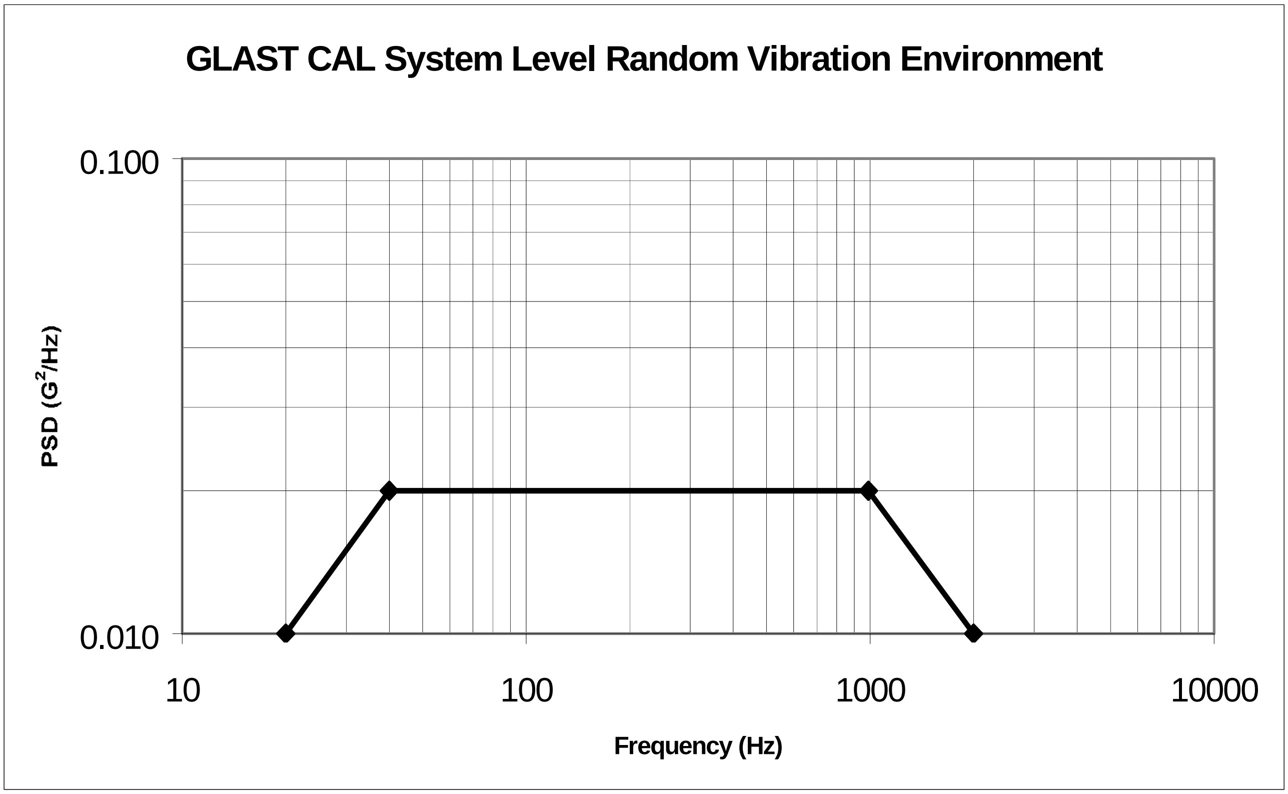
0.5 gRMS	
Frequency (Hz)	g^2/Hz
20	0.000125
50	0.000125
800	0.000125
2000	0.000125

Levels Apply to all Horizontal and Vertical Axes

Figure 6-1: Low-Level Random Vibration Environment

6.2 RANDOM VIBRATION TEST LEVEL

Each axis of FM 101 was independently subjected to the random vibration environment shown in Figure 6-2, which is specified in Table 25 of the LAT Environmental Specification, LAT-SS-00778. The structure was subjected to –12 dB and –6 dB random vibration levels preceding the full-level random vibration test.



Protoflight Levels

5.8 gRMS

Frequency (Hz)	g^2/Hz
20	0.010
40	0.020
990	0.020
2000	0.010

Test Duration: 1 minute per axis

Levels Apply to all 3 Axes

Figure 6-2: GLAST CAL System Level Random Vibration Environment

6.3 SINE-SWEEP TEST LEVEL

All three axes of the CAL Tower Module were independently subjected to the sine-sweep environment shown in Table 6-1, which is specified in Table 21 of the LAT Environmental Specification, LAT-SS-00778.

Table 6-1: GLAST CAL System Level Sine-Sweep Test Level

LAT CAL Protoflight Test Levels			
Axis	**Freq. (Hz)**	**Test levels**	**Sweep Rate [Oct/min]**
Thrust (Z)	5 - 20	2.5 g	4
	25 - 35	5.9 g	4
	40 - 50	2.1 g	4
Lateral (X&Y)	5 - 15	2.7 g	4
	15 - 25	1.2 g	4
	25 - 35	1.2 g	4
	35 - 43	1.5 g	4
	43 - 50	1.9 g	4

Notes: (1) Quarter and Half Level Tests will be performed before testing at full levels
(2) Linear acceleration transition from 2.5g's at 20 Hz to 5.9g's at 25 Hz.
(3) Linear acceleration transition from 5.9g's at 35 Hz to 2.0g's at 40 Hz.

6.4 SINE BURST TEST LEVEL

All three axes of the QM CAL Tower Module were independently subjected to a static-equivalent qualification acceleration level using a sine-burst test level defined in Table 6-2, which is specified in Table 4 of the LAT Environmental Specification, LAT-SS-00778.

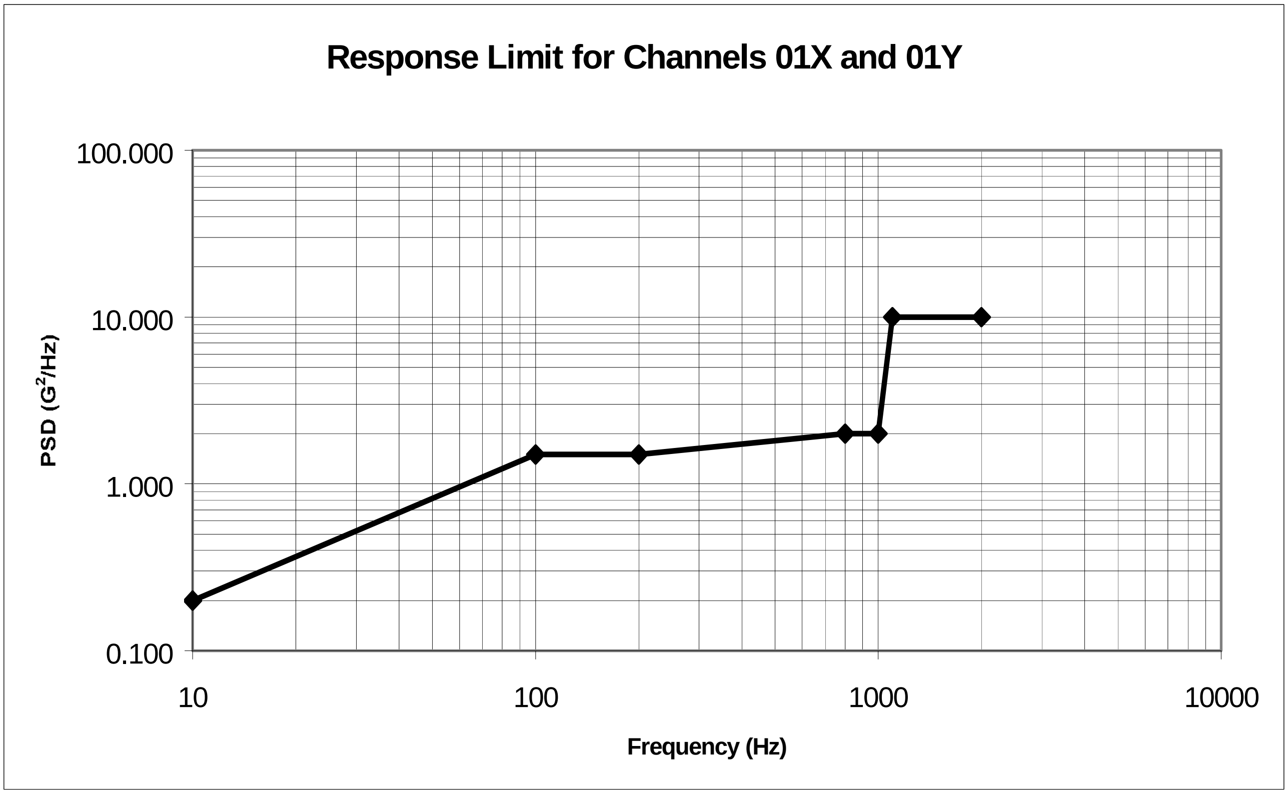
Table 6-2: GLAST CAL System Sine Burst Test Level

Axis	Frequency	Acceleration	Cycles
X (Transverse)	25 Hz	$\pm$ 7.5	5
Y (Transverse)	25 Hz	$\pm$ 7.5	5
Z (Thrust)	25 Hz	$\pm$ 8.5	5

6.5 LIMITING ACCELERATIONS

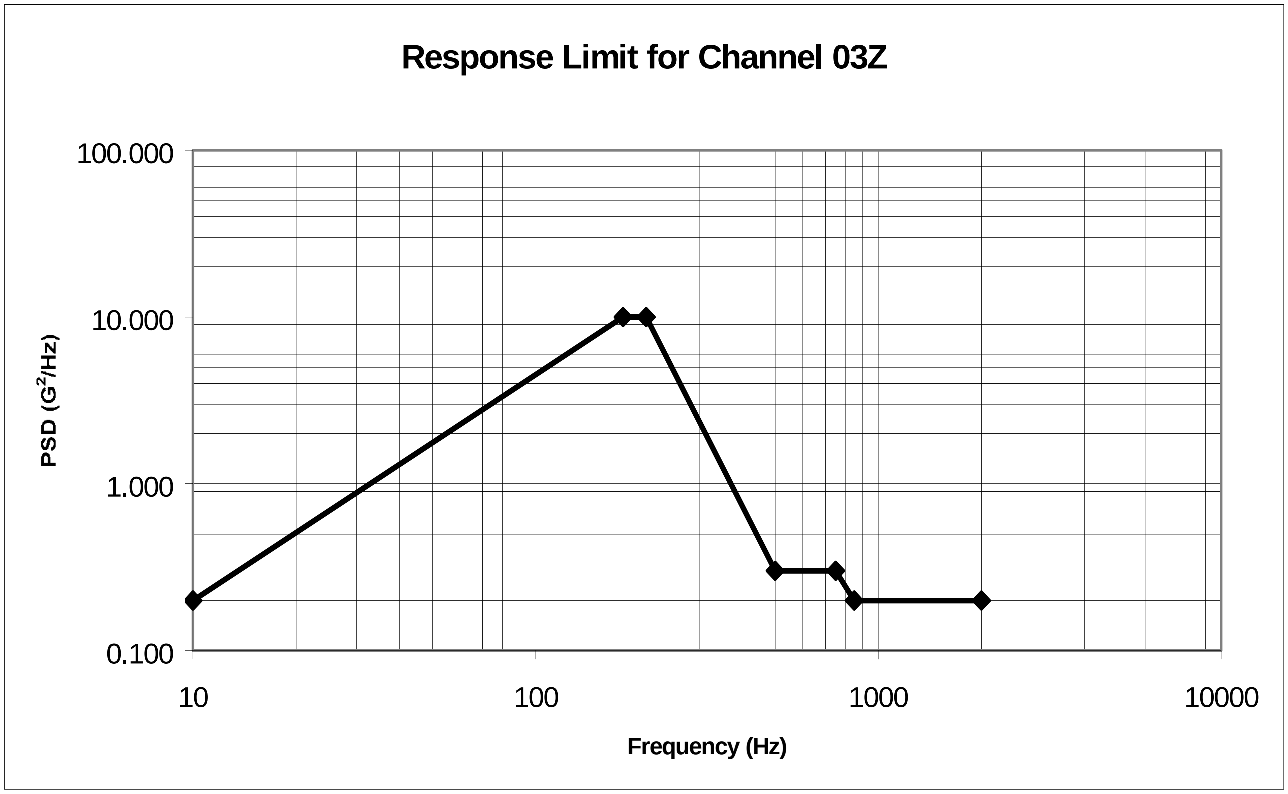
The notching criteria used for this test was based on test results from the CAL Module EM Vibration Test (LAT-TD-01888). Responses were limited to prevent them from exceeded the responses observed during the EM test. Levels were automatically controlled using response limiting. Accelerometers at the interface will also be controlled to prevent amplification due to the test fixture.

Expected notching criteria may change based on responses observed during the –6 db and –12 db vibration events. If so, any changes to the control and/or response limit levels would be verified prior to running at full level vibration.



Frequency (Hz)	g^2/Hz
10	0.200
100	1.500
200	1.500
800	2.000
1000	2.000
1100	10.000
2000	10.000

Figure 6-3: Response Limit for Channels 01X and 01Y



Frequency (Hz)	g^2/Hz
10	0.200
180	10.000
210	10.000
500	0.300
750	0.300
850	0.200
2000	0.200

Figure 6-4: Response Limit for Channel 03Z

7 TEST SEQUENCE AND RESULTS

7.1 TEST SEQUENCE OF THE TEST FIXTURE

Prior to testing of FM 101, the strength of the test fixture was confirmed and its dynamic behavior was characterized in order to certify control accelerometer locations and verify the pre-test analytical predictions. Testing of the test fixture began on April 22, 2003 (prior to EM CAL vibration test). Results of this test are found in LAT-TD-01888, CAL Module, EM Vibration Test Report.

7.2 TEST SEQUENCE OF THE TEST ARTICLE

The FM 101 was tested in accordance to WOA-01379. The test article was tested in the order of X-Axis, Y-Axis, and Z-Axis. Table 7.2-1 through Table 7.2-3 summarizes the test sequence conducted for each axis of the test article.

7.2.1 X-Axis Test Phase

In preparation for the first test phase, the test article was installed onto the test fixture/vibration table in the X-Axis configuration. Weight of the test article was measured (89.2 kg) using a calibrated scale.

X-axis testing began on September 22, 2004. The fundamental frequencies and frequency signature of the test article was characterized during low-level random vibration (0.5 gRMS, 20-2000 Hz) runs. Low-level random vibration was applied to the test fixture, as specified in Figure 6.1. Expected primary frequency is approximately 180 Hz, based on analysis and confirmed during the CAL EM vibration test, as documented in LAT-TD-01888. The first fundamental frequency was identified as 195 Hz. Plotted data of the input and frequency response to the low-level input is found in Appendix A1.

Failure of the channel ID 05X of the accelerometer ID 05 occurred at the beginning of the test. After consultation between the test team, it was decided to proceed with the test due to the following:

- Accelerometer was located on a non-flight component
- Location of the accelerometer made it difficult to replace without disassembly of test set-up
- Similar accelerations at this location could be measured during the Y-Axis Test phase using channel ID 05Y.

Random Vibration levels were applied at –12 dB, -6 dB, and full level, 20-2000 Hz, as specified in Figure 6.2. Response limits, as defined from results of the EM CAL Module vibration test documented in LAT-TD-01888-01, were applied. Based on observed responses during the reduced-level random vibration at –12 dB and –6 dB runs, no modifications to the response limits were necessary. However, during the –12 dB run, it was noted that the shaker was driving harder in the high-frequency range in order to achieve the desired response at the CAL module interface. After consultation with the test team, it was decided to add two additional control accelerometers to the test fixture base plate. This would allow the system to control off the primary control accelerometers (located at the CAL module interface) until the higher frequencies are reached. At this point, the higher frequencies are no longer important, as far as the test requirements are concerned, and the system controls off the control accelerometers on the test fixture base plate. This control scheme was used for the rest of the test. After modification to the shaker control, full-level testing occurred without a problem. Plotted data of the input and frequency response is found in Appendix A2.

Sine-sweep test levels were applied at –6 dB and full level, 8-50 Hz. The starting frequency of 5 Hz, as specified in Table 6-1, was updated to 8 Hz since it violated the stroke limitation of the shaker. Since no problems were seen in the –12 dB level during the random vibration test, it was decided to skip the planned –12 dB sine-sweep run and use the –6 dB run to determine if the modified control scheme was also valid for the sine-sweep test. No problems were observed during the –6 dB run. Full-level testing also occurred without a problem. Plotted data of the input and frequency response is found in Appendix A3.

Sine Burst started at a low-level of –15 dB, and incrementally increased at 3 dB steps prior to full level, as specified in Table 6.1. Full-level testing also occurred without a problem. The highest accelerations on the test article were observed at the +Z surface of the CAL Module, ±7.7 gpk. Plotted data of the input and acceleration response is found in Appendix A4.

The pre-test and post-test frequency signatures for the X-axis were superimposed and plotted in Appendix A5. Minimal amplitude changes between the pre- and post-test signatures indicated that crystal shifting occurred within the structure. However, there were no significant frequency changes between these two signatures indicating that the structure of the CAL Module is sound.

7.2.2 Y-Axis Test Phase

Following the X-axis test, the test article was, rotated 90-degrees, and re-bolted into place for the Y-axis test.

Y-axis test began on September 23, 2004. The fundamental frequencies and frequency signature of the test article was characterized during low-level random vibration (0.5 gRMS, 20-2000 Hz) runs, as specified in Figure 6.1. The first fundamental frequency was identified as 200 Hz. Plotted data of the input and frequency response to the low-level input is found in Appendix B1.

Random Vibration levels were applied at –12 dB, -6 dB, and full level, 20-2000 Hz, as specified in Figure 6.2. The same response limits used for the X-axis test were also applied to the Y-axis test. Based on observed responses during the reduced-level random vibration at –12dB and –6 dB runs, no modifications to the response limits were necessary. Full-level testing also occurred without a problem. Plotted data of the input and frequency response is found in Appendix B2.

Sine-sweep test levels were applied at –6 dB and full level, 8-50 Hz. As with the X-axis test, the starting frequency of 5 Hz, as specified in Table 6-1, was also updated to 8 Hz. Full-level testing also occurred without a problem. Plotted data of the input and frequency response is found in Appendix B3.

Sine Burst started at a low-level of –15 dB, and incrementally increased at 3 dB steps prior to full level, as specified in Table 6.1. Full-level testing also occurred without a problem. The highest accelerations on the test article were observed at the +Z surface of the CAL Module, ±7.7 gpk. Plotted data of the input and acceleration response is found in Appendix B4.

The pre-test and post-test frequency signatures for the Y-axis were superimposed and plotted in Appendix B5. Minimal amplitude changes between the pre- and post-test signatures indicated that crystal shifting occurred within the structure. However, there were no significant frequency changes between these two signatures indicating that the structure is sound.

7.2.3 Z-Axis Test Phase

Prior to the third test phase, the primary test fixture was secured onto the expander-head of the vertical shake table. The test article was suspended over the test fixture and re-bolted into place for the Z-axis test.

Z-Axis test began on September 24, 2004. The fundamental frequencies and frequency signature of the test article was characterized during low-level random vibration (0.5 gRMS, 20-2000 Hz) runs, as specified in Figure 6.1. The first fundamental frequency was identified as 205 Hz. Plotted data of the input and frequency response to the low-level input is found in Appendix C1.

Random Vibration test levels were applied at –12 dB, -6 dB, and full level, 20-2000 Hz, as specified in Figure 6.2. Response limits, as defined from results of the EM CAL Module vibration test documented in LAT-TD-01888-01, were applied. Based on observed responses during the reduced-level random vibration at –12dB and –6 dB runs, no modifications to the response limits were necessary. Full-level testing occurred without a problem. Plotted data of the input and frequency response is found in Appendix C2.

A slight projection at 160 –170 Hz above the response limit was observed on accelerometer channel 05Z during the –12 dB run, but the test continued with the response automatically controlled. During the –6 dB random vibration run, the response was automatically limited in the 1600 Hz-2000 Hz range on channel 05Z per response limits, as specified in Figure 6.4-4. Full-level testing occurred without a problem with automatic limits occurring in the high frequency range.

Sine-sweep test levels were applied at –6 dB and full level, 8-50 Hz. The starting frequency of 5 Hz, as specified in Table 6-1, was also updated to 8 Hz. Full-level testing occurred without a problem. Plotted data of the input and frequency response is found in Appendix C3.

Sine Burst started at a low-level of –15 dB, and incrementally increased at 3 dB steps prior to full level, as specified in Table 6.1. Full-level testing also occurred without a problem. The highest accelerations on the test article were observed at the +Z surface of the CAL Module, +8.4/-8.3 gpk. Plotted data of the input and acceleration response is found in Appendix C4.

The pre-test and post-test frequency signatures for the Z-axis were superimposed and plotted in Appendix C5. Minimal amplitude changes between the pre- and post-test signatures indicated that crystal shifting occurred within the structure. However, there were no significant frequency changes between these two signatures indicating that the structure is sound.

Following the Z-Axis test, the test article was unbolted from the test fixture and installed into the shipping container for transportation to the functional test area.

7.2.4 Comprehensive Functional Testing

Following vibration test sequence for all axes, FM 101 underwent comprehensive functional performance testing as well as cosmic muon collection, in accordance with LAT-PS-01513, CAL Functional Test and Calibration Procedure, to verify the function of the AFEE and TEM electronics.

Initially, the AFEE would not power up for the test. After extensive troubleshooting, as documented in problem report, PRB-0420, it was determined that the power supply of the TEM-TPS (s/n FM01) assembly did not survive vibration testing. Upon replacement of the power supply with that from s/n FM08, as documented in WOA-01394, FM 101 successfully completed comprehensive functional performance testing and cosmic muon collection.

Table 7-1: X-Axis Test Sequence for the Test Article

Run #	Test Description	Frequency (Hz)	Test Level	Duration	Comments
1	Low-Level Random Vibration (Pre-Test Signature)	Input: 0.5, gRMS 20 Hz -2000 Hz	See Section 6.1	As Required for Data	Identify modal frequency
2, 3	Random Vibration (-12 dB, -6 dB)	Input: 20 Hz –2000 Hz	See Section 6.2	As Required for Data	Verify Notching Criteria
4	Random Vibration (Full Level)	Input: 20 Hz –2000 Hz	See Section 6.2	1 Minute (minimum)	Notch if Required
5	Sine-Sweep (-6 dB)	Input: 5 Hz – 15 Hz, 15 Hz – 25 Hz, 25 Hz – 35 Hz, 35 Hz – 43 Hz, 43 Hz – 50 Hz	See Section 6.3		
6	Sine-Sweep (Full Level)	Input: 5 Hz – 15 Hz, 15 Hz – 25 Hz, 25 Hz – 35 Hz, 35 Hz – 43 Hz, 43 Hz – 50 Hz	See Section 6.3		
7	Sine-Burst (-15 to -3 dB)	Input:, 25 Hz	See Section 6.4	5 Cycles	
7	Sine-Burst (Full Level)	Input: $\pm$7.5 gpk, 25 Hz	See Section 6.4	5 Cycles	
8	Low-Level Random Vibration (Post-Test Signature)	Input: 0.5, gRMS 20 Hz -2000 Hz	See Section 6.1	As Required for Data	Compare Pre and Post FRFs

<u>NOTE</u>: Run 1 and 8: Maximum allowable frequency shift between the pre- and post-test measurement of the fundamental frequency must be within 10%.

Table 7-2: Y-Axis Test Sequence for the Test Article

Run #	Test Description	Frequency (Hz)	Test Level	Duration	Comments
9	Low-Level Random Vibration (Pre-Test Signature)	Input: 0.5, gRMS 20 Hz -2000 Hz	See Section 6.1	As Required for Data	Identify modal frequency
10, 11	Random Vibration (-12 dB, -6 dB)	Input: 20 Hz –2000 Hz	See Section 6.2	As Required for Data	Verify Notching Criteria
12	Random Vibration (Full Level)	Input: 20 Hz –2000 Hz	See Section 6.2	1 Minute (minimum)	Notch if Required
13	Sine-Sweep (-6 dB)	Input: 5 Hz – 15 Hz, 15 Hz – 25 Hz, 25 Hz – 35 Hz, 35 Hz – 43 Hz, 45 Hz – 50 Hz	See Section 6.3		
14	Sine-Sweep (Full Level)	Input: 5 Hz – 15 Hz, 15 Hz – 25 Hz, 25 Hz – 35 Hz, 35 Hz – 43 Hz, 45 Hz – 50 Hz	See Section 6.3		
15	Sine-Burst (-15 to -3 dB)	Input:, 25 Hz	See Section 6.4	5 Cycles	
15	Sine-Burst (Full Level)	Input: $\pm$7.5 gpk, 25 Hz	See Section 6.4	5 Cycles	
16	Low-Level Random Vibration (Post-Test Signature)	Input: 0.5, gRMS 20 Hz -2000 Hz	See Section 6.1	As Required for Data	Compare Pre and Post FRFs

NOTE: Run 1 and 8: Maximum allowable frequency shift between the pre- and post-test measurement of the fundamental frequency must be within 10%.

Table 7-3: Z-Axis Test Sequence for the Test Article

Run #	Test Description	Frequency (Hz)	Test Level	Duration	Comments
17	Low-Level Random Vibration (Pre-Test Signature)	Input: 0.5, gRMS 20 Hz -2000 Hz	See Section 6.1	As Required for Data	Identify modal frequency
18, 19	Random Vibration (-12 dB, -6 dB)	Input: 20 Hz –2000 Hz	See Section 6.2	As Required for Data	Verify Notching Criteria
20	Random Vibration (Full Level)	Input: 20 Hz –2000 Hz	See Section 6.2	1 Minute (minimum)	Notch if Required
21	Sine-Sweep (-6 dB)	Input: 5 Hz – 20 Hz, 25 Hz – 35 Hz, 40 Hz – 50	See Section 6.3		
22	Sine-Sweep (Full Level)	Input: 5 Hz – 20 Hz, 25 Hz – 35 Hz, 40 Hz – 50	See Section 6.3		
23	Sine-Burst (-15 to -3 dB)	Input:, 25 Hz	See Section 6.4	5 Cycles	
23	Sine-Burst (Full Level)	Input: $\pm$8.5 gpk, 25 Hz	See Section 6.4	5 Cycles	
24	Low-Level Random Vibration (Post-Test Signature)	Input: 0.5, gRMS 20 Hz -2000 Hz	See Section 6.1	As Required for Data	Compare Pre and Post FRFs

NOTE: Run 1 and 8: Maximum allowable frequency shift between the pre- and post-test measurement of the fundamental frequency must be within 10%.

7.3 SUMMARY OF THE RESULTS

The first three fundamental frequencies of the test article, as shown in Table 7.4, were summarized from plotted data found in Appendix A through Appendix C.

Acceleration response to the static-equivalent acceleration load provided by the sine burst, as shown in Table 7.5, was summarized from plotted data found in Appendix A4, Appendix B4, and Appendix C4.

For each axis, pre-test and post-test frequency signatures were compared. Overlays of pre-test and post-test signatures are found in Appendix A5, Appendix B5, and Appendix C5. Minimal amplitude changes between the pre- and post-test signatures indicated that crystal shifting occurred within the structure. However, there were no significant frequency changes between these two signatures indicating that the structure of the CAL Module is sound.

Following structural environmental testing, a comprehensive performance test of the AFEE and TEM electronics was performed. Problems with the TEM-TPS are addressed in problem report, PRB-0420. Upon replacement of the faulty power supply, this test was successfully performed in accordance with LAT-PS-01513, *CAL Functional Test and Calibration Procedure*.

Table 7-4: Fundamental Frequencies of FM 101

Accelerometer ID	**Accelerometer Location**	**1st Fundamental Frequency** (Hz)
Acceleration in X-Direction		
1	-X Side Panel, Top	195
2	-Y Side Panel, Top	195
3	+Z Structure	195
5	-Z TEM Power Supply, Center	n/a
Acceleration in Y-Direction		
1	-X Side Panel, Top	200
2	-Y Side Panel, Top	200
3	+Z Structure	200
5	-Z TEM Power Supply, Center	260
Acceleration in Z-Direction		
1	-X Side Panel, Top	210
2	-Y Side Panel, Top	205
3	+Z Structure	210
5	-Z TEM Power Supply, Center	210

Table 7-5: Sine Burst Response

Accelerometer ID	Accelerometer Location	Acceleration Response (g)	
Acceleration in X-Direction			
1	-X Side Panel, Top	+7.7	-7.7
2	-Y Side Panel, Top	+7.6	-7.6
3	+Z Structure	+7.7	-7.7
5	-Z TEM Power Supply, Center	n/a	n/a
Acceleration in Y-Direction			
1	-X Side Panel, Top	+7.6	-7.6
2	-Y Side Panel, Top	+7.5	-7.5
3	+Z Structure	+7.7	-7.7
5	-Z TEM Power Supply, Center	+7.5	-7.8
Acceleration in Z-Direction			
1	-X Side Panel, Top	+8.0	-8.2
2	-Y Side Panel, Top	+8.0	-8.1
3	+Z Structure	+8.4	-8.3
5	-Z TEM Power Supply, Center	+8.2	-8.2

8 CONCLUSIONS

The FM 101 CAL Module passed this series of vibration testing since the following criteria, as specified in LAT-PS-04454, *CAL Flight Module Vibration Test Procedure*, were met:

- The protoflight test levels were applied in accordance with the test levels and limits specified in Table 6.1, Figure 6.1 through Figure 6.4 of LAT-PS-04454.
- The GLAST CAL Module did not incur damage.
    - Pre- and Post- Frequency Response Functions indicated no significant changes in dynamic response (less than 10% frequency shift).
    - Visual inspections showed no physical damage.
- Acquisition of data was recorded
- Successful Comprehensive Performance Test of the AFEE and TEM electronics, in accordance with LAT-PS-01513, *CAL Functional Test and Calibration Procedure*, following completion of applied test levels.
- Successful cosmic muon tests, in accordance with LAT-PS-01513, *CAL Functional Test and Calibration Procedure*, following Comprehensive Performance Test